

ASSESSMENT OF THE ACCURACY OF DEM FROM PANCHROMATIC PLEIADES IMAGERY (CASE STUDY: BANDUNG CITY. WEST JAVA)

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Abstract. Pleiades satellite imagery is very high resolution. with 0.5 m spatial resolution in the panchromatic band and 2.5 m in the multispectral band. Digital elevation models (DEM) are digital models that represent the shape of the Earth's surface in three-dimensional (3D) form. The purpose of this study was to assess DEM accuracy from panchromatic Pleiades imagery. The process conducted was orthorectification using ground control points (GCPs) and the rational function model with rational polynomial coefficient (RFC) parameters. The DEM extraction process employed photogrammetric methods with different parallax concepts. Accuracy assessment was made using 35 independent check points (ICPs) with an RMSE accuracy of ± 0.802 m. The results of the Pleiades DEM image extraction were more accurate than the National DEM (DEMNAS) and SRTM DEM. Accuracy testing of DEMNAS results showed an RMSE of ± 0.955 m. while SRTM DEM accuracy was ± 17.740 m. Such DEM extraction from stereo Pleiades panchromatic images can be used as an element on base maps with a scale of 1: 5.000.

Keywords: *Pleiades. Digital Elevation Model. Stereo. Accuracy*

1 INTRODUCTION

Remote sensing satellites and Earth observation satellites are currently used in various applications. including mapping. resource management. disaster simulation. and recently in geo-online applications such as Google Earth (Bignone & Umakawa, 2008). Satellite imagery continues to improve from low resolution to very high resolution. Since 2000. the development of optical sensors with very high resolution such as IKONOS. QuickBird and GeoEye has been rapid. with Pleiades being very high-resolution satellites recently launched (Benarchid. Raissouni. Adib. Abbous. Azyat. Achhab. Lahraoua. Chahboun. 2013). Pleiades satellite imagery comprises high-resolution optical images used for Earth observation missions with civil and military purposes, under the

development of the Centre National d'Etudes Spatiales (CNES). CNES is the French space agency, and develops satellites with very high resolution. This study involves one satellite that provides panchromatic and multispectral high resolution images (Baillarin, Panem, & Cazalet, 2012). In the panchromatic band. Pleiades satellite imagery has a spatial resolution of 0.5 m. and 2 m in its multispectral band (Aryani, Harto, & Soeksmantono, 2017).

The Pleiades are examples of very high resolution (VHR) satellites. VHR is superior to the resolution of other satellites in producing DEMs. VHR optical satellites offer the most widely available overlapping area and B/H ratio in stereo images. which results in exceptional image matching accuracy and in the resulting DEM. In addition. the

opportunity to revisit frequencies every 3 to 5 days increases the ongoing monitoring of variations in the Earth's surface (Deilami & Hashim, 2011)

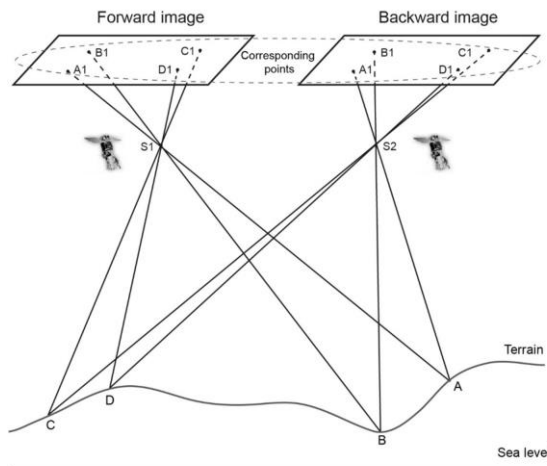


Figure 1-1: Principle diagram of DEM generation from stereo imagery (Wang et al., 2019).

The basic theory for obtaining DEMs using satellite stereo images is to synchronise feature points according to overlapping images and to produce coordinates in the 3D position of these points. then to reconstruct the spatial stereo model further and obtain 3D information according to the actual position on the ground (Figure 1-1) (Wang, Ren, Wu, Lei, Gong, Ou, Zhang, Huiping, 2019). The Pleiades provide a rational polynomial coefficient (RPC) file containing a rational function model that represents the relationship between objects and image coordinates (Doloff & Theiss, 2014). The ratio polynomial is defined as follows:

$$L = L_s \times \frac{NUM_1(U.V.W)}{Den_1(U.V.W)} + L_0.S$$

$$= S_s \times \frac{NUM_s(U.V.W)}{Den_s(U.V.W)} + S_0 \quad (1-1)$$

$$\frac{NUM_1(U.V.W)}{Den_1(U.V.W)} \cdot \frac{NUM_s(U.V.W)}{Den_s(U.V.W)}$$

where is the normalised image coordinates; (U.V.W) are the normalised ground coordinates; ($L_s.S_s$) is the normalised proportional parameter; and

($L_0.S_0$) is the normalised translation parameter. $Num_1(U.V.W)$, $Den_1(U.V.W)$, $Num_s(U.V.W)$, and $Den_s(U.V.W)$ can be expressed as the following polynomials:

$$m = a_1 + a_2V + a_3U + a_4W + a_5VW + a_6VW$$

$$+ a_7UW + a_8V^2 + a_9U^2 + a_{10}W^2 + a_{11}UVW \quad (1-2)$$

$$+ a_{12}V^3 + a_{13}VU^2 + a_{14}VW^2 + a_{15}V^2U +$$

$$a_{16}U^3 + a_{17}UW^2 + a_{18}V^2W + a_{19}U^2W$$

$$+ a_{20}W^3$$

All the coefficients of the four polynomial functions are stored in one file containing 80 rational polynomial coefficients (RPCs). through which the ground coordinates can be calculated.

The spatial resolution of the Pleiades satellites makes them an alternative choice for creating a digital elevation model (DEM). In principle. DEMs are digital models that represent the shape of the Earth's surface in three dimensions (Indarto & Prasetyo, 2014). DEMs can be obtained by various techniques such as stereo photogrammetry from aerial photo surveys. Light Detection and Ranging (LiDAR). Interferometric Synthetic Aperture Radar (IFSAR). and mapping surveys. Other methods that can be used to produce DEMs include RTK-GPS. block adjustments from satellite imagery and topographic maps (Naim, Abdullah, & Hashim, 2014).

This study aims not only to determine the accuracy of the results of the DEM extraction using panchromatic Pleiades satellite imagery. but also to determine the scale that matches the resulting DEMs. The method used is extraction. which in mainly employs the parallax concept. The scope of the research is limited to the following issues:

1. The data used are Pleiades panchromatic satellite stereo image acquired in July 2014.
2. Nine ground control points (GCPs) are used for orthorectification of the images.

3. The orthorectification process uses the rational function model (RFM) method with rational polynomial coefficient (RPC) parameters.
4. 36 independent check points (ICPs) are used to test the accuracy of the DEM extraction results.

2 MATERIALS AND METHODOLOGY

2.1 Data

The Pleiades satellite system was designed for both civil and military purposes under the French-Italian ORFEO (Optical & Radar Federated Earth Observation) program in 2001-2003. The constellation comprises two satellites, Pleiades 1A and Pleiades 1B, operating in the same phased orbit. The data used in this study were panchromatic Pleiades stereo images acquired on 17 July 2014. Detailed product parameters are shown in Figures 2-1 and 2-2.

Product Parameters			
Product Id	DS_PHR1B_201407170319013_IP3_PX_E107S07_0803_00992		
Acquisition date	2014-07-17 03:19:36.4		
Platform	PHR 1B		
Band ID	PA		
	Incidences and orientation		
	start	middle	end
	179.9747768	179.9812635	180.0486867
	9.826442716	9.894546537	9.963007981
	-6.149603156094127 / -7.722987556	-6.246824334654747 / -7.733928909	-6.351652715977125 / -7.738542377

Figure 2-1: Product Parameters of Left-hand Side Image

Product Parameters			
Product Id	DS_PHR1B_201407170319304_IP3_PX_E107S07_0803_00987		
Acquisition date	2014-07-17 03:20:05.5		
Platform	PHR 1B		
Band ID	PA		
Incidence and orientation			
	start	middle	end
Orientation	179.9655127	180.0307129	180.130577
Global incidence	13.81085112	13.86180214	13.91234192
Accross / along the track	-9.854213176964146 /	-9.937346268356288 /	-10.01376001475964 /
incidence	9.867501346	9.858379709	9.855044538

Figure 2-2: Product Parameters of Right-hand Side Image

2.2 Location

The research location was the city of Bandung, West Java, Indonesia, located at latitude 6°55' south and longitude 107°36' east. The total area of Bandung City is 16.729.65 Ha. The location can be seen in Figure 2-3.

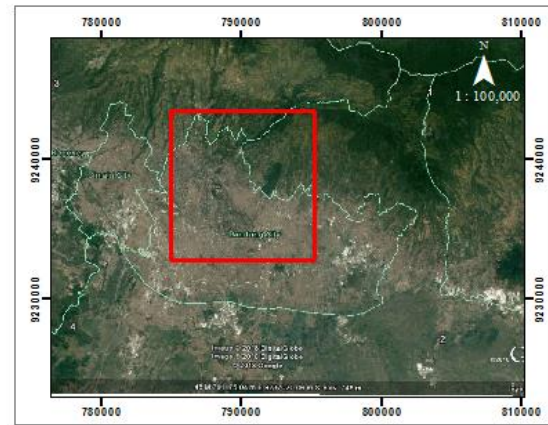


Figure 2-3: Research Area (shown in red rectangle)
(Source: Google Earth.2018)

2.3 Methods

The implementation of the research consisted of several steps (Figure 2-4):

1. Panchromatic Pleiades Stereo Images.

This study uses panchromatic Pleiades stereo image data with a spatial resolution of 0.5 m (see Figures 2-5A and 2-5B).

2. Image Orthorectification.

An image orthorectification process was conducted to reduce the effect of geometric distortion of objects on the images, using nine ground control points (GCPs) obtained by GPS measurements. The distribution of the GCPs can be seen in Figure 2-6 (shown by yellow dots).

Subsequently the root mean square error (RMSE) was calculated. The orthorectification process was performed using the rational function model (RFM) method (Rudianto, 2011), with rational polynomial coefficient (RPC) parameters. In the implementation of image orthorectification, the RMSE value must comply with the tolerance, which is calculated by Algorithm 0.5 x spatial resolution (Rudianto, 2011), accordingly, the tolerance to comply requirements is ≤ 0.25 m.

3. Epipolar Images

Epipolar images are stereo pairs in which the left and right images are oriented in such a way that ground feature points have the same coordinates on both images. Using epipolar images removes one dimension of variability, thus greatly increasing the speed of image-matching processing as well as the reliability of the matching results.. Hence epipolar images are used for the extraction of the DEM.

4. DEM extraction

The stages of DEM extraction are as follows:

- Convert raw images to epipolar images.
- DEM extraction from the epipolar images. The result of this stage is a DEM which has not been georeferenced.
- DEM geocoding, which is the process of forming georeferenced DEMs.

5. Accuracy Test

An accuracy test was then performed using 36 independent check points (ICPs) obtained from the GPS measurement results (shown as red dots in Figure 2-7).

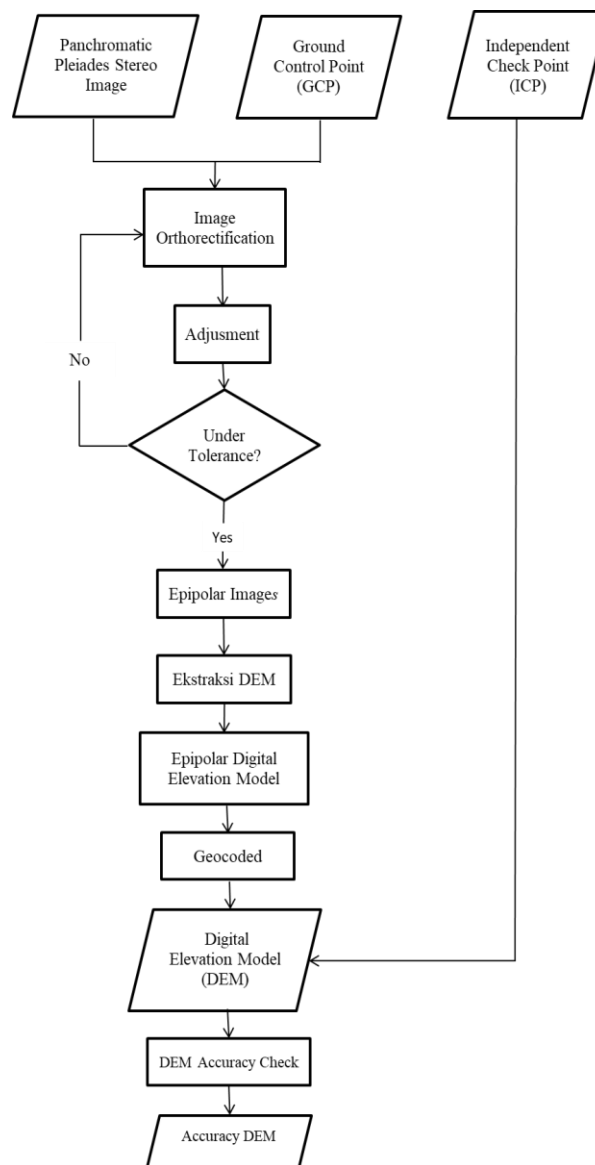


Figure 2-4: Research Flowchart



Figure 2-5A: Left-hand Side Image

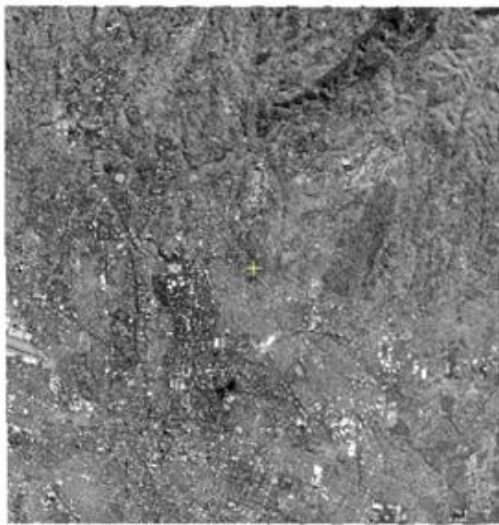


Figure 2-5B. Right-hand Side Image

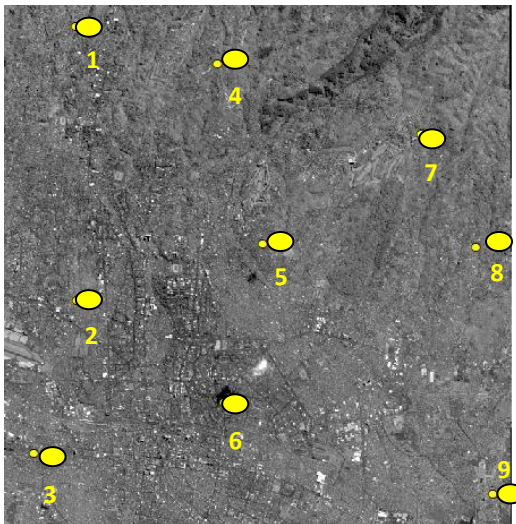


Figure 2-6. Distribution of GCPs

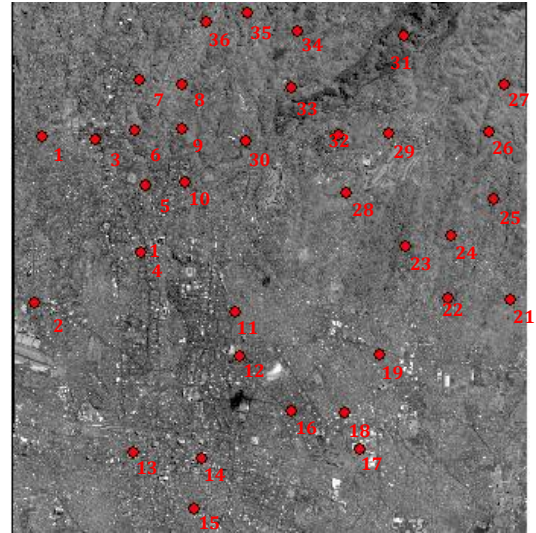


Figure 2-7: Distribution of ICPs

3 RESULTS AND DISCUSSION

The DEM extraction research using panchromatic Pleiades satellite imagery produced a DEM map. The research results can be seen in Figure 3-1.

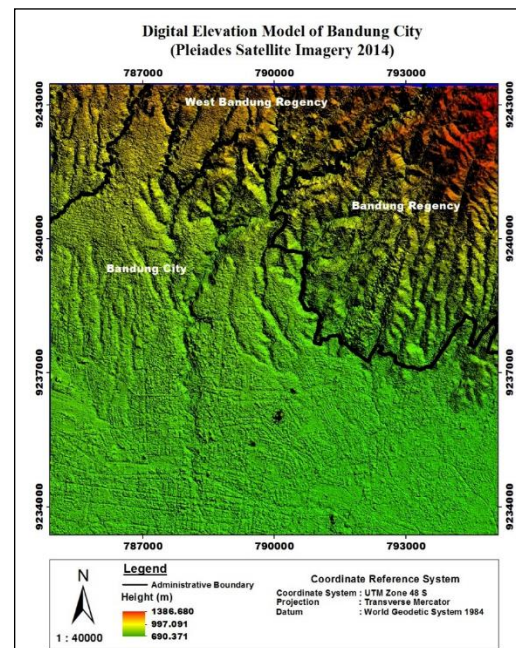


Figure 3-1: Digital Elevation Model Map

The DEM extraction results provide information on a height range of 690.70 m-1386.68 m (Figure 3-1). DEM surface roughness shows the surface representation of the city of Bandung.

The orthorectification process employed nine GCPs. The results of the process can be seen in Table 3-1. By using nine GCPs, an RMSE of 0.218 m (Equation 3-1) was obtained, therefore complying with the tolerance used. The DEM accuracy testing process was then conducted, with the results using high ICP data shown in Table 3-2.

$$RMSE_{horizontal} = \sqrt{\frac{\sum(\Delta X)^2 + (\Delta Y)^2}{n}} \quad (3-1)$$

n = number of sample observations

ΔX = difference in the coordinates of the x-axis observations and models

ΔY = difference in the coordinates of the y-axis observations and models

$$RMSE_{vertical} = \sqrt{\frac{\sum(\Delta Z)^2}{n}} \quad (3-2)$$

n = number of sample observations

ΔZ = difference in the coordinates of the Z-axis observations and models

Table 3-1: Orthorectification Results

GCP	ΔX (m)	ΔY (m)	$(\Delta X^2 + \Delta Y^2)$
GCP9	0.160	0.180	0.058
GCP59	0.180	-0.140	0.052
GCP90	-0.050	0.100	0.0125
GCP16	0.110	0.180	0.0445
GCP45	-0.010	-0.050	0.0026
GCP76	-0.050	0.150	0.025
GCP22	0.230	0.290	0.137
GCP41	0.180	-0.130	0.0493
GCP91	-0.040	0.200	0.0416
$\Sigma =$			0.3809
RMSE=			0.218

Z GCP is the coordinate height of the GCP point. Z Pleiades is the coordinate height obtained from DEM extraction.

and ΔZ is the coordinate difference between the height of the extraction result (model) and the GCP height (GPS). An accuracy test was performed using 35 independent check points (ICPs) and an RMSE (Equation 3-2) of 0.802 m was generated. The level of accuracy was influenced by Bandung's topographical conditions. For example, ICP11, ICP5 and ICP24 displayed high accuracy, while the level of accuracy was not so good at low levels, for example ICP26, ICP34 and ICP97. The highlands generally comprise open land, while the lowlands generally consist of buildings and settlements, facts which affect noise when recording and consequently the level of accuracy.

In this study, an accuracy test for the national DEM and SRTM DEM was also performed. The accuracy of the test results for the DEMNAS image produced an RMSE of ± 0.955 m, while the test results on the SRTM image produced an RMSE of ± 17.740 m.

Furthermore, the accuracy of the vertical geometry was calculated using the linear error (LE90) (Equation 3-3) formula obtained from Perka BIG Number 6 of 2018. The calculation process was as follows:

$$\begin{aligned} \mathbf{LE90} &= \mathbf{1.6499 \times RMSE_z} \\ &= 1.6499 \times 0.802 \\ &= 1.323 \end{aligned} \quad (3-3)$$

After calculation, vertical accuracy was used to determine the scale of the base map that corresponds to the magnitude of LE90. The vertical accuracy standards can be seen in Table 3-3.

Table 3-2: GPS and Pleiades DEM Accuracy Test Results

No.	ICP	Z GCP/Z ₁ (m)	Z Pleiades/Z ₂ (m)	(ΔZ^2)
1.	ICP51	816.883	816.746	0.019
2.	ICP26	886.426	889.912	12.155
3.	ICP3	987.997	987.571	0.181
4.	ICP34	856.929	858.606	2.811
5.	ICP48	812.813	811.914	0.808
6.	ICP42	831.725	831.052	0.453
7.	ICP87	721.956	722.415	0.211
8.	ICP15	965.263	965.973	0.505
9.	ICP30	903.376	903.839	0.215
10.	ICP84	706.705	706.001	0.496
11.	ICP21	1141.258	1141.464	0.206
12.	ICP11	1260.063	1260.165	0.101
13.	ICP28	935.231	934.199	-1.031
14.	ICP18	1005.249	1005.691	0.442
15.	ICP88	728.064	728.804	0.740
16.	ICP17	1017.145	1018.033	0.889
17.	ICP63	714.930	715.563	0.634
18.	ICP60	774.584	774.409	-0.174
19.	ICP31	936.756	937.104	0.348
20.	ICP66	751.702	752.240	0.537
21.	ICP75	719.183	719.182	-0.001
22.	ICP24	956.858	956.781	-0.077
23.	ICP74	711.489	711.995	0.506
24.	ICP29	927.524	927.430	-0.095
25.	ICP5	1088.176	1088.154	-0.022
26.	ICP27	942.342	942.050	-0.293
27.	ICP97	716.974	717.792	0.818
28.	ICP7	1102.241	1102.826	0.585
29.	ICP38	872.076	872.101	0.024
30.	ICP43	855.554	856.628	1.074
31.	ICP52	743.244	743.152	-0.092
32.	ICP37	862.308	862.050	-0.259
33.	ICP23	941.857	941.906	0.049
34.	ICP56	773.491	773.577	0.086
35.	ICP6	1118.624	1118.295	-0.329
			$\Sigma=$	22.5207
			N=	35
			RMSE=	0.802

Table 3-3: Vertical Accuracy Standards

No.	Map Scale	Vertical Accuracy (m)		
		Class 1	Class 2	Class 3
1	1 : 10000	2	3	4
2	1 : 5000	1	1.5	2
3	1 : 2500	0.5	0.75	1

(Source: (Perka BIG, 2018))

Based on the accuracy of the DEM Pleiades test results using high ICP an RMSE value of 0.802 was obtained. with the LE90 result being 1.323. According to Perka BIG No. 6 of 2018 concerning Technical Guidelines for the Accuracy of Basic Maps. the results of the extraction of DEMs from panchromatic Pleiades stereo images can be used as a base map with a scale of 1: 5000 with class 2 accuracy. in which the maximum permissible accuracy allowed is 1.5 m.

4 CONCLUSION

The conclusion that can be drawn from the results of the study is that the DEM extraction using panchromatic Pleiades stereo imagery and GCP for orthorectification stages has a tolerable RMSE value. The value generated at the orthorectification stage was ± 0.218 m. The accuracy of the test results using ICP obtained an RMSE value of ± 0.802 . The results of the Pleiades DEM image extraction were more accurate compared to that of the national or SRTM DEMs. Testing of the accuracy of the national DEM resulted in a RMSE of ± 0.955 m. while for SRTM DEM it was RMSE ± 17.740 m.

According to Perka BIG No. 6 of 2018 concerning the Technical Guidelines for the Accuracy of Basic Maps. the test results can be used for base maps on a 1: 5000 scale. with class 2 accuracy. namely 1.5 m.

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AUTHOR CONTRIBUTIONS

Assessment Of The Accuracy Of Dem From Panchromatic Pleiades Imagery (Case Study: Bandung City. West Java). Lead Author: Rian Nurtyawan, Co-Author: Nadia Fiscarina.

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